THE LEAD PHASEDOWN: AN ALTERNATIVE DEMAND FOR ETHANOL AS AN OCTANE ENHANCER

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ABSTRACT

Ethanol from corn is an important U.S. renewable energy source. In 1986, about 3.3 billion liters of ethanol were used, primarily as a gasoline extender. With lead phasedown, ethanol (octane rating of 113-116) is being considered as an alternative octane source. First, octane requirements following enactment of lead phasedown regulations are determined. Competing octane sources are then analyzed under various oil price, corn price and policy (subsidies, import tariffs) scenarios. At corn price levels of \$59.05 - \$68.90 MT and oil prices of \$16-\$26 per barrel, a subsidy of \$0.07-\$0.105 per liter would be necessary for ethanol to compete with other octane enhancers. Potential demand for ethanol could approach 10.7 billion liters per year. A tariff of \$0.035-\$0.071 per liter on imported ethanol (net of subsidy) would be necessary to protect this potential market for U.S. corn based ethanol.

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INTRODUCTION

In recent years, fuel grade ethanol has emerged as a source of renewable energy from agricultural products. The initial objective of the ethanol fuel program in the early 1980s was to reduce dependence on foreign supplies of energy. At that time, the prospect of using surplus corn as a feedstock provided important agricultural industry support, leading to incentives for the production and use of ethanol from biomass as well as tariffs to restrict imports of lower cost Brazilian ethanol. In response to these incentives, significant amounts of capital investment have taken place principally in the Midwest region where most corn production is located [1].

In 1986, about 3.32 billion liters of ethanol were used nationwide, primarily as a gasoline replacement. About 7.6 million MTs of corn (4% of total production) were processed into ethanol with 90% of the production capacity located in the midwest.

While the recent decline in oil prices has dampened the prospects for ethanol as a gasoline replacement, environmental regulations to reduce, and eventually eliminate lead content in gasoline provide ethanol with an important new role as an octane source. Many oil refiners face difficulties meeting their current gasoline octane requirements, while

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the growing demand for unleaded premium gasoline will further increase these octane requirements.

Ethanol fuel has an octane rating of 113-116, and whether it is used as a gasoline replacement or as an octane enhancer, this octane value is realized in the resulting fuel mixture [2,3]. When used as a gasoline replacement (the current principal use), this octane value is not fully utilized as part of the octane pool, nor adequately reflected in the market price of ethanol. In many cases, the higher octane fuel is simply sold in the regular fuel market. However, in the future, ethanol, along with other octane enhancers, can provide a significant portion of the refineries' future octane needs. Competing octane sources include aromatic octane enhancers such as benzene and toluene and oxygenates such as MTBE.

In this paper, a parametric linear programming model is used to estimate the potential demand for ethanol as an octane source in the U.S. fuel market and to address policy issues related to its production and use. Octane requirements are estimated for gasoline refineries. The potential octane number for producing octane at the refinery level and the potential supply of independently produced octane enhancers including ethanol are determined for short (1990) and medium (1995) time frames.

LEAD PHASEDOWN AND GASOLINE QUALITY

Octane rating (resistance to self ignition) is the most important aspect of gasoline quality and historically, lead has been an important source of raising octane level. The U.S. Environmental Protection Agency (EPA) regulated gasoline lead content reduction to 0.023 grams per liter effective January 1986 [4]. To facilitate the process of reducing lead content in gasoline, the EPA issued lead banking regulations where refiners using less than permitted quantities of lead were allowed to use their deficit in future periods. Trading in lead banking rights was permitted by the EPA. Octane number requirements have also been increased by the growing demand for unleaded premium, up 5-6 percent annually in recent years.

Volatility is an important quality consideration. This characteristic, indicated by the gasoline Reed Vapor Pressure (RVP), is crucial to engine cold starting ease and freedom from vapor lock. In many cases, when refiners upgrade gasoline octane rating either through refinery processing methods or using fuel additives, RVP often increases above the desired level. The solution is to reduce high volatility components in gasoline composition such as butane. To remove butane or to reduce the RVP by one PSI, the cost ranges between $0.002 and $0.003 per liter [5]. However, the cost of adjusting the RVP may be insignificant because the octane rating is increased [6].

ESTIMATING OCTANE REQUIREMENTS

Projections for future gasoline demand vary depending on number of vehicles, miles traveled, fuel efficiency and future gasoline prices. Available forecasts for periods through 1995, however, do not take into account the effect of the recent decline in oil prices [7,4,8,9]. In this analysis, prior EPA projections were adjusted to reflect changes in oil prices with a gasoline price elasticity of demand of -.15 [10]. Oil prices studied include $10, $16, $20, $26, $30 and $35 per barrel.

The loss of gasoline octane number due to a reduction of 0.234 gram of lead additive per liter is about 1.41 octane numbers for each liter.

The annual increase in the total octane pool due to the growth of unleaded premium gasoline is estimated at 219 million octane number barrels (ONB/year) [11]. Estimates of octane requirements following lead phasedown are made for two time periods: 1990 and 1995. The short run (1990) represents the initial full impact of lead phasedown which is assumed to be delayed because of lead banking. The medium run (1995) includes allowance for the unleaded premium gasoline market and the ability to adjust supply responses for each of the competing octane sources. The estimates of both short and medium run octane number barrel requirements for alternative oil prices for the U.S. are displayed in Table 1.

ALTERNATIVE SOURCES TO PROVIDE GASOLINE OCTANE REPLACEMENT REQUIREMENTS

Several options are available to meet octane number replacement requirements following lead phasedown. They include: (1) refining gasoline at increased severity, (2) constructing or expanding existing processing equipment, and (3) purchasing high octane additives. The options vary by refinery depending on a number of factors including the particular configuration and excess capacities of each refinery, the economic costs of octane enhancers and the price of crude oil.

Upgrading gasoline octane number rating through reforming, isomerization, or other refinery processing routes is the most attractive option for most refiners, especially at low oil prices. Others, particularly small independent refiners, do not have excess processing capacities or the financial ability to invest in new octane upgrading facilities. They will use octane number enhancers to upgrade their gasoline octane. There are two types of octane enhancers, aromatics which have been used traditionally and oxygenates including ethanol. Aromatics include toluene, benzene and xylene (TBX).

Oxygenates include MTBE (methyle tetiary butyl ether), ethanol, methanol and the Dupont Waiver (methanol mixed with a co-solvent such as ethanol in a ratio of 2:1). These oxygenates are blended with gasoline in volumes of 7.5 to 16 percent depending on their effect on gasoline quality. Although methanol has a high octane number rating, it can not be used without a co-solvent because of corrosive problems.

STUDY MODEL

A parametric cost minimization linear programming model was used to estimate the potential demand for ethanol as an octane source. The cost of providing gasoline refiners in the U.S. with their octane number needs were minimized subject to supply and other constraints. Model parameters were varied according to alternative oil price levels and other policy variables such as subsidy level, tariffs on ethanol imports and corn prices. Since octane capability differs among alternative octane sources for the same volume unit, supply and cost data are converted into a unified measure, octane number barrel (ONB). The following equation is used to estimate the cost of ONB for each octane source:

$$\text{Cost (\$/ONB)} = \frac{OC - GP}{B - A}$$

where:

OC = the cost of the octane source, $/liter

GP = the cost of gasoline, $/barrel

B = product octane of the octane source (octane rating)

A = original octane rating of gasoline

The ONB cost for each alternative is calculated taking into account the economic cost of adjusting RVP and the energy loss (BTU), where applicable [5]. The potential demand is estimated on both a national and regional basis. The U.S. refinery sector is divided into five regions according to the Petroleum Administration Defense District Classification (PADD) (Figure 1). The costs of transporting ONB from production to consumption regions are also included in the analysis. The basic mathematical formulation of the model is as follows:

minimize: $$Z = \sum_h \sum_j U_{hj} Y_{hj} + \sum_e \sum_i \sum_j (a_{ei} + c_{eij} - S_e) X_{eij} + \sum_j \sum_f (b_f + c_{fj} + t_f) X_{fj}$$ subject to

octane requirement constraint $$\sum_e \sum_i X_{eij} + \sum_f X_{fj} + \sum_h Y_{hj} = D_j$$

refinery processing capacity constraint $$Y_{hj} < Q_{hj}$$

domestic octane enhancer supply constraint $$\sum_j X_{eij} < M_{ei}$$

imported octane enhancer supply constraint $$\sum_j X_{fj} < P_f$$

non-negativity $$X_{eij},\ X_{fj},\ Y_{hj} > 0$$

where: Z = the total ONB cost to meet U.S. refineries octane number demand

e = domestic octane enhancer, $e = 1,2...n$

i = region where octane enhancer is produced, $i = 1,2...5$

j = region where octane enhancer is consumed, $j = 1,2...5$

f = country exporting ethanol, $f = 1,2$

h = type of refinery processing, $h = 1,2$

x_eij = amount domestic octane enhancer e used (million ONB/year) in region j and produced in region i

$x_f j$ = amount of octane enhancer inported from country f and used (million ONB/year) in region j

$Y_h j$ = amount of octane processed at refinery h and used in region j (million ONB/year)

D_j = octane requirements for region j

$Q_h j$ = octane production capacity from refinery type h (million ONB/year) in region j

$M_e i$ = octane supply capacity from domestic octane source e (million ONB/year) in region i

P_f = octane supply capacity from exporting country f (million ONB/year)

U_{hj} = cost of producing one ONB from internal processing h in region j (million ONB/year)

a_{ei} = cost of producing one OBN from enhancer e in region i ($/ONB)

c_{eij} = cost of transporting one ONB of enhancer e from region i to j ($/ONB)

S_e = subsidy provided to octane enhancer e ($/ONB)

b_f = cost of producing one ONB of imported octane enhancer from country f ($/ONB)

cfj = cost of transporting one ONB of octane enhancer from country f to region j

t_f = tariff imposed on octane enhancer from country f ($/ONB)

MODELS ANALYZED

A baseline model was constructed to represent the demand for ethanol in an assumed situation of no government intervention in the ethanol market and with expected prices for corn ($68.90/MT) and oil ($20/barrel). Other formulations of the model reflect oil and corn price changes and alternative ethanol policy measures such as subsidy levels for domestic ethanol and tariffs imposed on ethanol imports.

Combinations of these scenarios are also formulated to examine the effect of the interaction among the changing variables on the demand for fuel ethanol. As mentioned earlier, two time periods: the short run (1990) and the medium run (1995) are considered. The results for all scenarios are published in Ahmed.

COST AND SUPPLY CAPACITY CONSTRAINTS OF ALTERNATIVE OCTANE SOURCES

Supply constraints for alternative octane number options along with their costs are the major determinants of their level of use in the model. Producing octane via processing is constrained by capital requirements and the time needed for capacity expansion. Oxygenates such as MTBE or ethanol are constrained principally by the availability and cost of feedstocks and secondarily by the ability to expand production capacity. Projections concerning the potential supply are based on the best available data and judgment of industry experts.

Octane from Internal Processing

Upgrading the octane number through internal refining processes (reforming, isomerization, alkylation, fluid cat cracking, etc.) represents the most desirable option for a refiner. The cost of increasing octane rating vary by refinery type and prices of crude oil. At oil prices of $20 per barrel, the average cost for producing one octane number barrel (ONB) ranges between $0.13 to $0.29 for the different types of octane processing refineries. These data, which were derived from Weiszmann, were inserted into the objective function of the linear programming model [6]. Announced investments by refiners for modifications and additions of processing facilities to meet lead phasedown regulations will provide 62 percent of the octane replacement requirements [3].

Aromatic Octane Enhancers

Supply of aromatics such as toluene, benzene and xylene is a function of the refinery capability of processing, particularly reformate. Based on the potential increase in production and the level of demand in the chemical industry, the supply of aromatics for octane purposes was estimated at 1.967 billion liters a year by 1990 and 2.176 billion liters a year by 1995 [6].

Ethanol Fuel Supply Capacity

Domestic Ethanol

The current capacity of ethanol production in the U.S. is estimated at 3.576 billion liters per year [2]. Over 90 percent of production capacity is located in the Midwest the major corn producing region. Annual production has reached 3.2 billion liters. The cost for manufacturing ethanol depends on the price of corn, energy costs, size of plant and price of by-products (corn gluten meal, corn gluten feed and DDGS). At a corn price of $68.90 per MT, oil price of $20.00 per barrel and by-product prices of $105 per MT, the average cost for manufacturing ethanol is estimated at $0.319 per liter. The unit cost of ethanol will rise and fall as oil prices and/or corn prices increase or decline. Short run (1990) production capacity is projected at 5.63 billion liters annually, 50 percent above the current level. For 1995, a projected capacity of 10.67 billion liters is used [6].

Imported Ethanol

The U.S. imports ethanol fuel from Brazil and Caribbean countries. Total imports were estimated at 512 million liters in 1985. Brazil is the world's largest producer and the major exporter of ethanol fuel to the U.S. It currently produces over 12.8 billion liters annually, more than four times U.S. production, and is expected to reach 17.28 billion liters by 1989 [12]. Brazil uses sugar cane as a feedstock and the average cost of ethanol production in Brazil is estimated at $0.19 per liter. Export capacity of ethanol from Brazil to the U.S. is estimated to be about 2.987 billion liters annually by 1990 and 5.97 billion liters annually by 1995 [13].

Export capacity of Caribbean countries is small in comparison to Brazil, currently about 64 million liters annually. Caribbean ethanol export capacity by 1990 will not exceed 128 million liters annually and may reach 981.4 million liters by 1995 [14,15].

MTBE

MTBE, which is the most important oxygenate used by refiners has an annual production capacity of 4.56 billion liters, up almost three fold since 1984. Current production is 3.456 billion liters per year. MTBE is manufactured by mixing methanol with isobutylene. Methanol is abundantly available at very low prices, a condition expected to prevail well into the next decade. Isobutylene availability, on the other hand, is limited to that produced as a by-product from refining operations. Its supply has been almost fully utilized to produce MTBE. Other sources to produce isobutylene such as mixed butane and isobutane are limited by physical production capacity or economic constraint. The current production cost of MTBE ranges between $0.12 and $0.178 per liter depending upon the cost of feedstock. The potential production capacity of MTBE by 1990 is estimated by industry experts to be 5.76 billion liters annually, rising to 7.68 billion liters by 1995 [6].

Methanol

EPA regulations prohibit the use of pure methanol in gasoline, but permit co-solvent use, such as the DuPont Waiver which allows methanol-ethanol blends in gasoline at 5 and 2.5 percent, respectively. A major role for the DuPont Waiver as an octane source is not expected due to the effect of methanol on gasoline quality.

RESULTS AND ANALYSES

Capacity constraints, oil and corn price levels, and subsidy and tariff policies will be important determinants of the final mix of the octane source pool used to replace lead. As noted earlier, refinery processing is generally the most economical option to upgrade gasoline octane, particularly at oil prices between $10 and $26 per barrel (Figure 2). Within that range of oil prices, the projected potential capacities are used in almost all possible scenarios (Table 2). Aromatics are attractive options for the refiners at low oil prices also. However, the limitation on refinery supply of these traditional sources dictate the use of other alternative octane enhancers.

Of the remaining alternative sources, MTBE is the lowest cost and is more competitive than non-subsidized ethanol for all possible scenarios. However, short run MTBE production constraints due to limitations on feedstock availability and physical plant capacity would allow for limited use of non-subsidized ethanol. It is clear, however, that corn based ethanol would require subsidies in the $0.07-$0.105 per liter range to compete with MTBE (Table 3). Imported ethanol from Brazil is more competitive than corn based ethanol but less competitive than MTBE. An import tariff of $0.07 per liter on Brazilian ethanol is sufficient to exclude its use assuming it does not benefit from subsidy provided for domestic ethanol. Imported ethanol from Caribbean countries is not as competitive as Brazilian ethanol. Domestic ethanol is able to compete with Caribbean ethanol when the corn price is less than $68.90 per MT.

Currently, ethanol and MTBE are the two major potential sources to replace lead. While MTBE is the lower cost alternative, there are time and oil price factors that affect its competitiveness relative to ethanol. First, as oil prices rise, ethanol costs do not rise as rapidly as do the costs of MTBE. Within the ethanol pool, imported ethanol is the least sensitive to oil price changes, since sugar cane based ethanol produces its own processing energy. Oil price increases, however, also reduce demand for gasoline and hence dampen the demand for octane enhancers. Thus, oil price increases do not necessarily result in an increase in demand for ethanol in all situations.

Secondly, ethanol demand in the short run is more a factor of capacity limitations on production of MTBE. In the medium term, expansion in refinery octane processing capacity and MTBE production capacity require a higher level of ethanol subsidy to reach a similar ethanol use level.

Regional distribution of projected octane enhancer use in large part reflects transportation cost differences. Also, since refinery processing is site specific by refinery, there are regional differences in the relative amount of octane enhancer needs. The Midwest is the largest producer of U.S. ethanol (90%), and therefore enjoys a cost advantage in using corn based ethanol. Alternatively, imported ethanol would be used principally in coastal areas. The demand and production of MTBE are largest in the southwest region, the largest refinery region (Table 4).

CONCLUSIONS

Domestically produced fuel ethanol currently enjoys a market subsidy of about $0.187 per liter and is used primarily as a gasoline substitute. Both situations are expected to change. With lead phasedown and short run expected prices of corn and oil, domestically produced ethanol can fill a part of the octane pool, but would require a subsidy of about $0.07 per liter. Below that level, imported ethanol is less costly and would be the principal source for the ethanol component of the octane pool. Traditional sources of octane are the most competitive alternatives but are constrained by capacity and or feedstock supply. These constraints have been set above current estimates. Thus, the projected demand for ethanol is conservative.

Corn and oil prices both bear importantly on the level of ethanol demand. Several factors are related to oil price changes. First, as oil prices rise, there is a lowering of gasoline demand and hence less demand for octane enhancers. Also, with higher energy prices, production costs for corn based ethanol (U.S.) rise relative to sugar cane based ethanol (Brazil). Thirdly, ethanol becomes more competitive at higher energy prices relative to traditional non-lead octane alternatives.

Corn prices at each level of petroleum price are very important in determining the competitive position and necessary subsidy level for domestic ethanol production. With corn at $39.37 per MT, a subsidy of $0.035 per liter is sufficient to make U.S. corn ethanol competitive with imported ethanol at oil prices of $20 or less. At this oil price and a corn price of $68.90 per MT, the subsidy needed is $0.07 per liter. At a corn price of $98.42 per MT, a subsidy of $0.105 to over $0.141 per liter (depending on the price of oil) is needed to make U.S. corn ethanol competitive with imported ethanol. An import tax can reduce the competitiveness of Brazilian ethanol but will not eliminate the need for a subsidy for domestic corn ethanol.

If subsidy conditions are met, U.S. corn based ethanol faces a potential octane market of 4.3 - 10.7 billion liters annually over the next few years. The eventual size of that market, however, will depend on a number of technical, regulatory and supply constraint factors that remain to be determined.

POLICY IMPLICATIONS

Government Subsidy

Once ethanol is fully incorporated as a gasoline octane enhancer, the current subsidy level could be reduced substantially depending on other factors such as corn and oil prices. In general, the required subsidy would be in the range of $0.07 - 0.105 per liter. Therefore, state subsidies could be eliminated without affecting the competitiveness of ethanol <u>as an octane enhancer</u>. Elimination of the federal subsidy, however, would reduce significantly the ethanol production industry in the U.S.

The federal ethanol subsidy is given also to imported ethanol, but is then offset by an import tariff, except in the case of Caribbean ethanol which is imported duty free under the Caribbean Economic Recovery Act. A simpler administrative policy would be to change the federal excise tax exemption subsidy to a direct domestic producer subsidy, thus eliminating the need for the import tariff structure and the attendant regulatory costs.

Import Tariffs

The current level of import tariff -- $0.141 per liter -- is not prohibitive since it is more than offset by access to the combination of federal subsidy and some state subsidies. If the government subsidy were provided directly to domestic U.S. ethanol producers as suggested above, thus excluding foreign ethanol from the U.S. subsidy, an import tariff of $0.035 - 0.07 per liter, depending on oil prices, would be sufficient to deter ethanol imports.

A tariff on oil imports, which would increase the price of oil in the U.S. market, may increase the competitive position of ethanol relative to traditional octane enhancers. However, imported (Brazilian) ethanol would be more competitive than domestic ethanol if such a tariff is imposed. In this case the oil import tariff may need to be accompanied by a tariff on imported ethanol or an increase in the direct producer subsidy in order to maintain competitiveness of U.S. ethanol.

Corn Prices

The cost of corn could play an important role in determining the necessary level of government subsidy. The government could reduce the amount it pays as subsidy to ethanol producers by providing governmentowned corn (GOC) at a price below the statutory sale price by a value equal to the annual storage cost, currently in the range of \$9.85 - 11.82 per MT, an amount that could reduce the level of subsidy to ethanol by \$0.02 - 0.028 per liter. It must be noted, however, that this policy measure would be a short-run tool only, and its usefulness conditioned by the continued existence of a corn surplus.

On the other hand, some of the recently proposed farm policy alternatives which call for restricting the supply of agricultural products and as a means of increasing farm prices would have an adverse impact on the ethanol program. A successful implementation of this policy could reduce the corn supply and increase its price, which would increase the ethanol production costs and thus dampen the competitive position of domestic ethanol as an octane enhancer.

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TABLE 1
Annual Octane Requirements for U.S. Refineries Following Lead Phasedown Regulation

	Oil Price ($/barrel)					
	$10	$16	$20	$26	$30	$35
			(Million/ONB/year)[1]			
Short Run (1990)						
Midwest	1102	1040	998	978	904	853
Total U.S.	3950	3813	3659	3573	3316	3124
Medium Run (1995)						
Midwest	1344	1268	1217	1193	1102	1040
Total U.S.	4927	4649	4462	4357	4042	3811

[1] ONB is octane number barrels which represents the amount of octane needed to increase the octane rating of one barrel by one octane number.

TABLE 2

Estimated Octane Enhancer Demand as a Percent of Lead Octane Replacement

Corn Prices and Ethanol Subsidy Levels	Oil Prices ($/barrel) $16.00 Ethanol U.S.	Imports	MTBE	Other	$26.00 Ethanol U.S.	Imports	MTBE	Other	$35.00 Ethanol U.S.	Imports	MTBE	Other
					(Percent of Octane Replacement)							
					Short Run (1990)							
Corn Price $39.37/MT												
Zero Subsidy	11	7	17*	65	8	10	18*	64	4	16*	21*	59
$0.15/gal. subsidy	18	0	17*	65	13	8	18*	61	26	16*	21*	37
$0.30/gal. subsidy	22*	0	17*	61	23*	0	18*	59	26	16*	21*	37
$0.45/gal. subsidy	22*	0	17*	61	23*	0	18*	59	26	16*	21*	37
$0.60/gal. subsidy	22*	0	17*	61	23*	0	18*	59	26	16*	21*	37
Corn Price $68.90/MT												
Zero Subsidy	8	10	17*	65	0	13*	18*	69	0	16*	21*	63
$0.15/gal. subsidy	11	7	17*	65	8	10	18*	64	7	16*	21*	56
$0.30/gal. subsidy	18	7	17*	65	11	7	18*	64	26	16*	21*	37
$0.45/gal. subsidy	22*	0	17*	61	23*	0	18*	59	26	16*	21*	37
$0.60/gal. subsidy	22*	0	17*	61	23*	0	18*	59	26	16*	21*	37
Corn Price $98.42/MT												
Zero Subsidy	6	12	17*	65	0	13*	18*	69	0	16*	21*	63
$0.15/gal. subsidy	8	10	17*	65	0	13*	18*	69	0	16*	21*	63
$0.30/gal. subsidy	11	7	17*	65	7	10	18*	65	4	16*	21*	59
$0.45/gal. subsidy	18	0	17*	65	13	7	18*	62	26	16*	21*	37
$0.60/gal. subsidy	22	0	17*	65	23*	0	18*	59	26	16*	21*	37
					Medium Run (1995)							
Corn Price $39.37/MT												
Zero Subsidy	14	8	20*	58	8	10	21*	61	2	28*	24*	46
$0.15/gal. subsidy	22	0	20	58	15	7	21*	57	15	18	22	45
$0.30/gal. subsidy	23	0	20*	57	38*	0	20	42	44*	6	19	31
$0.45/gal. subsidy	36*	0	11	53	38*	0	20	42	44*	6	19	31
$0.60/gal. subsidy	36*	0	11	53	38*	0	20	42	44*	6	19	31
Corn Price $68.90/MT												
Zero Subsidy	11	11	20*	58	0	17	21*	62	0	28	24*	48
$0.15/gal. subsidy	14	8	20*	58	6	11	21*	62	3	28*	24*	45
$0.30/gal. subsidy	22	0	20*	58	15	8	21*	56	15	18	22	45
$0.45/gal. subsidy	23	0	19	58	38*	0	19	43	44*	9	16	31
$0.60/gal. subsidy	36*	0	11	53	38*	0	19	43	44*	9	16	31
Corn Price $98.42/MT												
Zero Subsidy	0	22	20*	58	0	17	21*	62	0	28	24*	48
$0.15/gal. subsidy	2	20	20*	58	0	17	21*	62	0	28	24*	48
$0.30/gal. subsidy	11	11	20*	58	6	11	21*	62	0	28	24*	48
$0.45/gal. subsidy	22	0	20*	58	15	8	21*	56	8	23	24	45
$0.60/gal. subsidy	22	0	20*	58	38*	0	21*	41	44*	9	16	31

* Represents projected maximum supply capacity of each alternative.
- U.S. ethanol: 5.26 billion liters in the short run and 10.62 billion liters in the medium run.
- Imported ethanol: 3.115 billion liters in the short run and 6.955 billion liters in the medium run.
- MTBE: 5.564 billion liters in the short run and 7.68 billion liters in the medium run.

TABLE 3
Estimated Demand for Alternative Octane Sources in the Short Run (1990) with Different Oil and Corn Prices and Subsidy Level for Domestic Ethanol

	OIL PRICES ($/Barrel)					
	$16	$20	$26	$16	$20	$26
	(billion liters)					
	Corn Price $68.90/MT			Corn Price $98.42/MT		
Subsidy Level Zero						
Ethanol U.S.	1.86	0.35	--	1.33	0.35	-
Ethanol Imports	2.57	3.11*	2.99	3.11	3.11*	2.99
MTBE	5.56*	5.56*	5.56*	5.56*	5.56*	5.56*
Others[1]	21.09*	21.09*	19.81*	21.09*	21.09*	21.09*
Subsidy Level $0.0.035/liter						
Ethanol U.S.	2.61	2.52	1.72	1.86	0.35	1.05
Ethanol Imports	1.83	2.35	2.32	2.57	3.11*	2.32*
MTBE	5.56*	5.56*	5.56*	5.56*	5.56*	5.56*
Others[1]	21.09*	19.19	19.81	21.09*	21.09*	20.69
Subsidy Level $0.07/liter						
Ethanol U.S.	4.44	4.98	2.97	2.61	0.478	1.46
Ethanol Imports	-	-	1.68	1.85	2.99	2.32
MTBE	5.56*	5.56*	5.56*	5.56*	5.56*	5.56*
Others[1]	21.09	19.19	18.86	21.09*	21.09*	20.08
Subsidy Level $0.015/liter						
Ethanol U.S.	5.27*	5.27*	5.27*	4.44	1.65	2.97
Ethanol Imports	-	-	-	-	2.35	1.68
MTBE	5.56*	5.56*	5.56*	5.56*	5.56*	5.56*
Others[1]	19.97	19.19	18.04	21.09*	20.42*	19.14
Subsidy level $0.14/liter						
Ethanol U.S.	5.27*	5.27*	5.27*	5.27*	5.27*	5.27*
Ethanol Imports	-	-	-	-	-	-
MTBE	5.56*	5.56*	5.56*	5.56*	5.56*	5.56*
Others[1]	19.97	19.19	18.25	19.97	19.19	18.25

* Represents the projected maximum supply capacity.

[1] Includes refinery processing and aromatic octane sources are measured in terms of MTBE equivalent in billion liters.

TABLE 4
Estimated Regional Octane Source Demand

Octane Source	East Coast	Midwest	South-West	Rocky Mt.	West Coast	Total U.S.
	Refinery Region					
			(billion liters)			
			Short Run (1990)			
Oil Price $16/bbl						
U.S. Ethanol	0.648	1.48	-	0.508	1.83	4.44
Imported Ethanol	-	-	-	-	-	-
MTBE	-	0.700	4.74	-	0.128	5.56
Aromatics	0.115	0.328	1.52	-	-	1.97
Oil Price $26/bbl						
U.S. Ethanol[1]	0.640	1.31	0.619	0.405	-	2.97
Imported Ethanol	0.597	0.700	-	-	1.68	2.98
MTBE	-	0.700	4.86	-	-	5.56
Aromatics	0.055	0.328	1.52	-	-	1.91
Oil Price $35/bbl						
U.S. Ethanol[1]	-	3.03	1.99	0.328	-	5.27
Imported Ethanol	0.307	-	1.46	-	1.22	2.99
MTBE	-	0.700	4.86	-	-	5.56
Aromatics	-	-	-	-	-	-
			Medium Run (1995)			
Oil Price $16/bbl						
U.S. Ethanol[1]	0.917	2.68	-	0.605	2.35	5.55
Imported Ethanol	-	-	-	-	-	-
MTBE	-	0.597	7.01	-	0.11	7.71
Aromatics	0.132	0.358	1.69	-	-	2.18
Oil Price $26/bbl						
U.S. Ethanol[1]	0.366	2.50	0.414	0.482	-	4.24
Imported Ethanol	-	-	-	-	2.14	2.14
MTBE	-	0.597	7.08	-	-	7.71
Aromatics	-	-	-	-	-	-
Oil Price $35/bbll						
U.S. Ethanol [1]	-	1.95	1.36	0.392	-	3.71
Imported Ethanol	0.636	-	2.09	-	1.58	4.30
MTBE	-	-	7.12	-	-	7.12
Aromatics	-	-	-	-	-	-

[1] U.S. Ethanol demand estimated at a subsidy level of $0.07 per liter and corn price of $68.90 per MT.

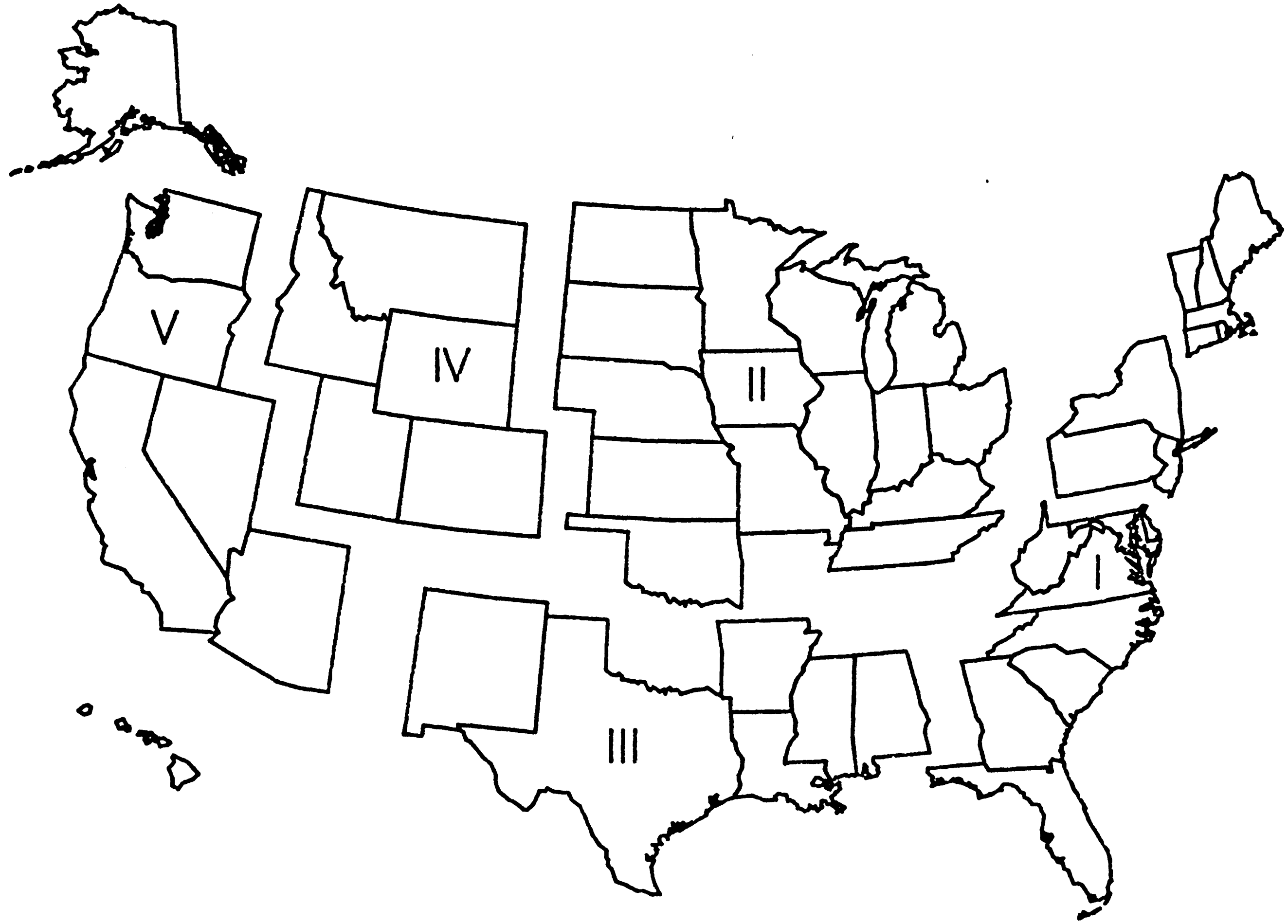

Figure (1) The U.S. Refinery Regions According to the Classifications of the Petroleum Administration for Defense District (PADD)

Figure (2) Cost of Alternative Octane Sources to U.S. Refineries at Current Capacity - 1987